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Title: The Analysis and Support for LANL Technology Testbed: High Altitude Balloon Gondola and Orion Eagle Gamma Ray Detection Instrument

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The Analysis and Support for LANL Technology Testbed: High Altitude Balloon Gondola and Orion Eagle Gamma Ray Detection Instrument.

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Abstract

The Analysis and Support for LANL Technology Testbed: High Altitude Balloon Gondola and Orion Eagle Gamma-Ray Detection Instrument is a project where Los Alamos National Laboratory (LANL), in conjunction with the University of Michigan, are looking into gamma-ray detection in a space-like environment. The purpose of the detection is to work on instruments that can assist with planetary exploration and nuclear deterrents using a High-Altitude Balloon (HAB). For this paper, the main focus is on the mechanical aspects related to the structural analysis of the gondola. It is vital to understand the structural analysis because it helps determine if the gondola can survive the changes in the environment and the different forces or shocks that it will experience when the parachute is deployed and at landing.

Additionally, NASA's Balloon Program Office (BPO) has specific requirements to meet to achieve flight certifications. Part of those certifications requires the gondola to simulate different scenarios at specific conditions with various forces applied and orientations. Therefore, it is necessary to adjust the calculations of each method and the force applied to get the right results. Once that is done, the information is inputted into the structural analysis modeling system. The system will aid the mechanical team in assessing the conditions of the gondola at each scenario and determine its margin of safety. After the gondola and instrument are certified, the payload will be able to fly. The HAB and payload are launched from NASA's Columbia Scientific Balloon Facility (CSBF) at Fort Sumner, NM. The official flight was on September 26th, 2021.

I. Introduction

High Altitude Balloons (HAB) or weather balloons are balloons filled with hydrogen or helium launched to reach the Stratosphere, usually floating at a cruise altitude of 120,000 feet or about 40 kilometers. The HAB is composed of three crucial parts, the balloon, a parachute, and the payload. The Stratosphere is part of the upper atmosphere and is the second atmospheric layer, and its environment resembles the one from Space. There are significant variations in temperature, pressure, and wind. Temperature can range from -76ºF to 68ºF, pressure ranges from 1.5 psi to 0.15 psi, and wind can reach speeds up to 120 mph as it cruises along the atmosphere[1]. Due to experiencing a space-like environment, the HAB has become an economical way for scientists to test different projects in those conditions.

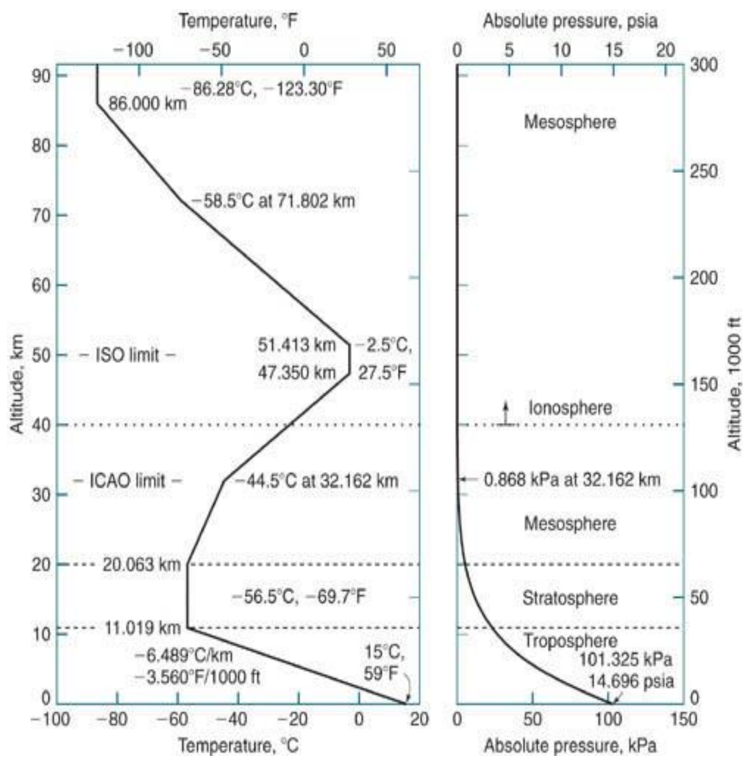

Figure 1: Atmospheric Change

Orion Eagle is a gamma-ray detector that uses a Cadmium, Zinc, and Tellurium (CZT) crystal capable of finding the gamma-ray particles. The use of a sensor like this would be helpful in planetary exploration, as it could provide imaging capabilities for the creation of detailed composition data[2].As mentioned before, it is essential to understand the environment to which the balloon will be subjected during its flight; this information is crucial for the design and fabrication of the gondola that will house the Orion Eagle detector. In addition, the mission must have a solid and insulated structure that will survive the drastic changes during flight.

For Orion Eagle's mission, the balloon will reach a cruise altitude between 100,000 – 120,000 feet, cruise at a temperature of -14ºF, a pressure of 0.4 psi, and float at cruise altitude for about 2 – 5 hours. Those conditions can alter the way the gondola and the detector are integrated. Furthermore, this project is being coordinated with NASA's Columbia Scientific Balloon Facility (CSBF) to meet the appropriate flight requirements to fly on a balloon. For that purpose, the project was broken into two sections Orion Eagle detector and gondola. The detector and the gondola are considered the payload of the HAB**.**

Figure 2: Orion Eagle Gondola and High Altitude Balloon

II. Orion Eagle Detector and Gondola Designs

A. Orion Eagle Detector

Orion Eagle detector's design is shown in Figure 3; the detector consisted of motherboard, High Voltage (HV) generation, ASIC, and crystal assembled to a main carrier board with copper thermal dissipators placed strategically to mitigate thermal concerns. Moreover, the CZT crystal was potted and enclosed, with the HV generation board and readout electronics enclosed in an additional metal box. This was to avoid HV concerns related to -3000V supply. Voltage is applied at the cathode surface in order to provide bias which makes the crystal functional[2]. The whole system was housed in an aluminum box, approximately 10 x 6 x 3.5” (26 x 16 x 9 cm).

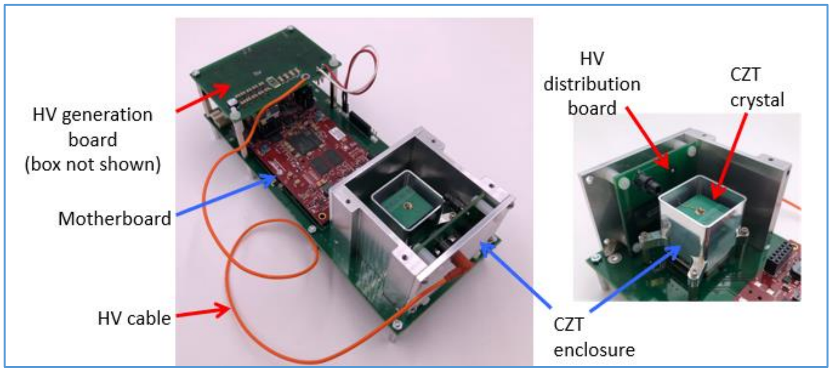

Figure 3: Orion Eagle Design.

Additionally, a relay board for communication with the CSBF support eletronics was included to command payload HV while in flight, not shown in Figure 3.

B. Gondola

The purpose of the gondola was to house the instrument, on-board computer, and power supply while providing proper insulation and mechanical isolation. In addition, the idea was to build something simple and cost effective capable of modification for re-use in the future. For that reason, the gondola was designed with materials that can be modular, rigid, but light enough to meet flight requirements.

Figure 4: Gondola with Orion Eagle Detector

1. Frame

The gondola had to meet specific flight requirements, and it was designed and analyzed with that in mind. These requirements consisted of the following: Cannot exceed 70 lbs., had to be able to have handles, and withstand four different scenarios for the attachment system that simulate the shock forces from parachute deployment. Cases are explained in detail within the analysis section.

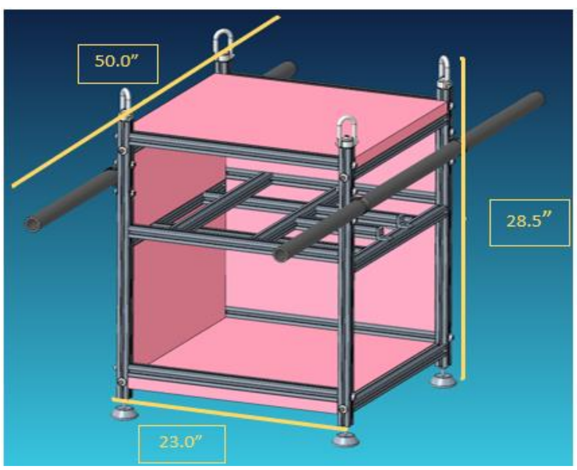

Figure 5: Gondola Dimensions

To ensure that the gondola would withstand the flight environment, the frame was assembled with ¼"-20 through-hole fasteners. As a result, the frame dimensions without feet were 20 x 20 x 24”. With feet, hoist rings, and handles installed dimensions were 23 x 50 x 28.5”.

The battery box was a commeercial off-the-shelf (COTS) rugged box capable of surviving changes in temperature and impact from landing. The box interior was insulated with R-5 grade insulation and soft ester foam to house the three flight batteries. The batteries were COTS flight-qualified batteries and provided 8000 mAh at 28V.

2. *Materials*

To meet future mission and flight requirements, it was necessary to investigate options that provided modularity and strength. The material selected for the structure was extruded aluminum T-slot (80/20) made of Al 6105-T5; the use of T-slot gives the gondola the modularity and rigidity needed for future missions with unknown mass distribution. Aluminum is a known material for its high strength to weight ratio[3]. Flight fasteners were 300 series stainless steel and ASME or equivalent certified. These materials are industry standard and used in many space missions. For insulation, the gondola used 1” polystyrene R-5 grade insulation. This is the same pink insulation used for houses. The handles were PVC tubes, hoist rings were Steel 4140, and wire rope isolators used are composed of stainless steel and aluminum.

The following table shows the mass for each component on the structural design:

Component	Mass (lb.)
Frame	28
Insulation	4
Battery Box	17
Computation	1
Orion Eagle	12
TOTAL	62
MASS NTE	70
Margin	8 (11.4%)

Table 1: Gondola Component Masses

3. *Layout*

The gondola layout was composed of two layers: the Top and Bottom, as seen in Figure 6. The top carried the Orion Eagle detector's aluminum box and the computer. Both were mounted on wire rope isolators to maintain the instrument's stability during shock events while assisting with thermal dissipation. Environemtnal sensors are included to collect in-flight data and hoist rings (tested to support 600 lbs. each) are used to connect the gondola to HAB suspension.

The bottom layer carried the insulated battery box and power connections to the detector and computer. The battery box was mounted upside-down to have easier access to the batteries. This allowed for a different modular design. The first iteration designed had crossbars at the bottom, and the box was mounted to them. While that seemed a feasible method, it proved inefficient when inserting the batteries into the box. A second iteration, with inverted battery box proved advantageous for operational use. It also allowed for maintaining the center of gravity at the middle of the gondola, which proved that it would have a uniform deformation and keeping the max stress in the middle, reducing strain from the joint sections on the frame. By reducing the strain from the joints it preserved the integrity of the overall structure and its rigidity.

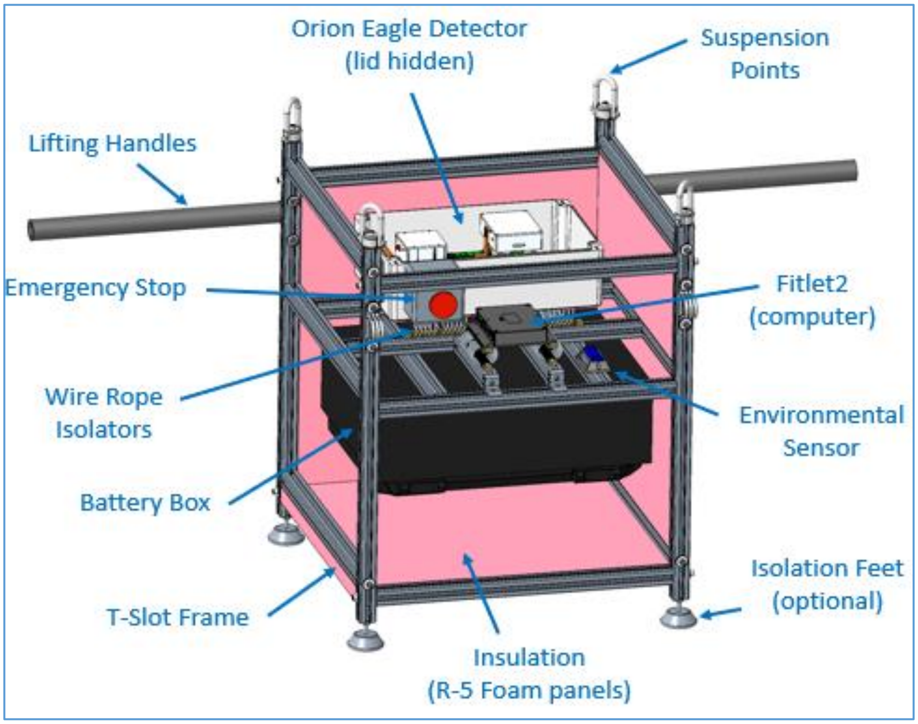

Figure 6: Gondola Layout

III. Analysis

The structural analysis of the gondola required a static simulation of four different scenarios per NASA's Balloon Program Office (BPO) flight requirements[4-5]. These scenarios' logic is based on the parachute opening shock and the forces applied to the hoist rings. The static analyses included: a vertical analysis, two 45-degree analyses, and a horizontal analysis[5].

Property	Value	Unit
Material Field Variables	Table	
~~Density~~	0.2836	lb in^-3
~~Isotropic Secant Coefficient of Thermal Expansion~~		
Coefficient of Thermal Expansion	6.6667E-06	F^-1
~~Isotropic Elasticity~~		
Derive from	Young's Modulus and Poiss...	
Young's Modulus	2.9008E+07	psi
Poisson's Ratio	0.3	

Table 2: Properties of AL 6061 T-6 MMPDS-09

The analyses were conducted using Finite Element Analysis (FEA) software. To understand how the calculations work, it was necessary to input the load applied, inertia relief, the gondola mass, and lastly, inputting the property information about the material. In this case, we used only the material used for the frame, Al 6105-T5. Since it was hard to find suitable properties for Al 6105-T5, we used the properties of AL 6061-T6. The properties of both materials are very similar and didn't change the expected results. Table 2 shows the properties needed for the analysis using Al 6061-T6.

The following chart demonstrates the Strain-Life Parameters of the Al 6061-T6. The Strain-Life Parameters method is used to understand how many cycles the material will last before failure.

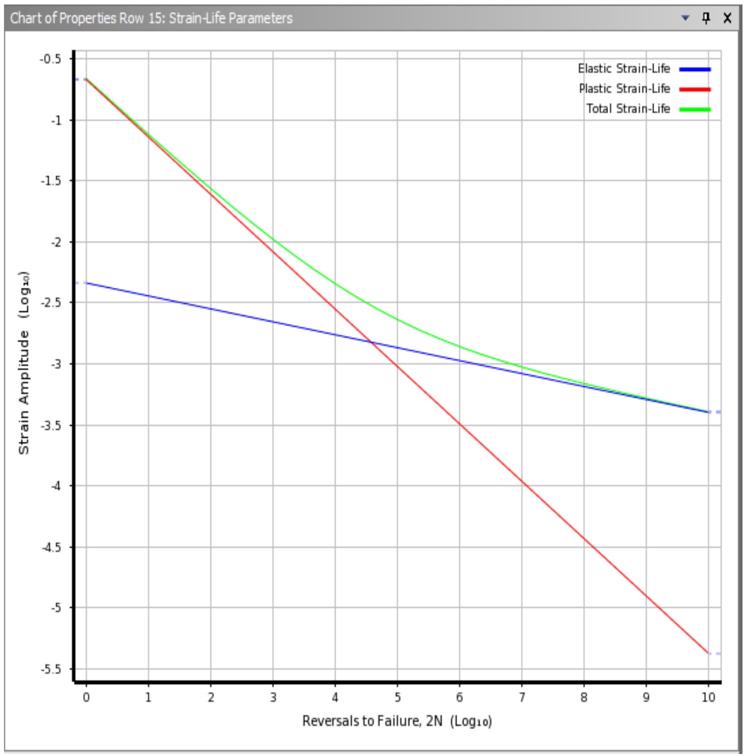

Chart 1: Strain-Life Parameters of Al 6061 T-6

A. Vertical Analysis

The vertical analysis is the first simulated scenario required to get the gondola Flight ready. Figure 7 shows the load case simulated in the FEA software. As seen in Figure 8, the simulation starts by fixing the base of the frame where the attachments were located—then multiplying the weight of the payload eight times to resemble the G forces that the frame would be experienced on the hoist rings and the top part of the frame during the parachute deployment. In this scenario, turning off the inertia relief was necessary, which is the balance of the force difference in a static analysis. Since we are applying acceleration to the whole body, it is needed to zero out the reaction on the vertical constrain. This is explained in the following equation:

$$Inertia\ Relief = \boldsymbol{F} - W = 0 \qquad \dots (1)$$

F – Forced applied

W – Weight

The information obtained from this analysis provided the Max stress that the frame would encounter during the parachute deployment. The information presented provides the information necessary to calculate the factor of safety needed to ensure the strength and integrity of the material caused by the stress of the shock. The results from this analysis showed that applying a load of 8G's would result in an acceleration of 257.54 ft/s^2 or 78.5 m/s^2 (shown in Figure 8),

4.2.1 Load Case #1

A load 8 times the weight of the payload applied vertically at the suspension point.

Rationale: Vertical load path for parachute opening shock immediately after termination. Optionally, pin base and apply vertical load.

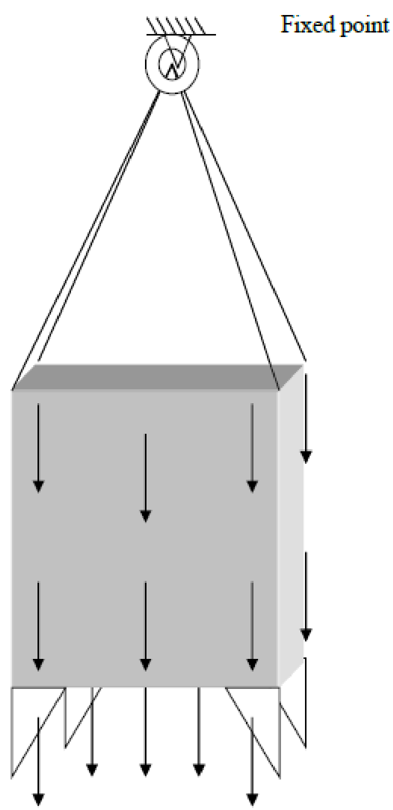

Figure 7: Gondola Vertical Loading

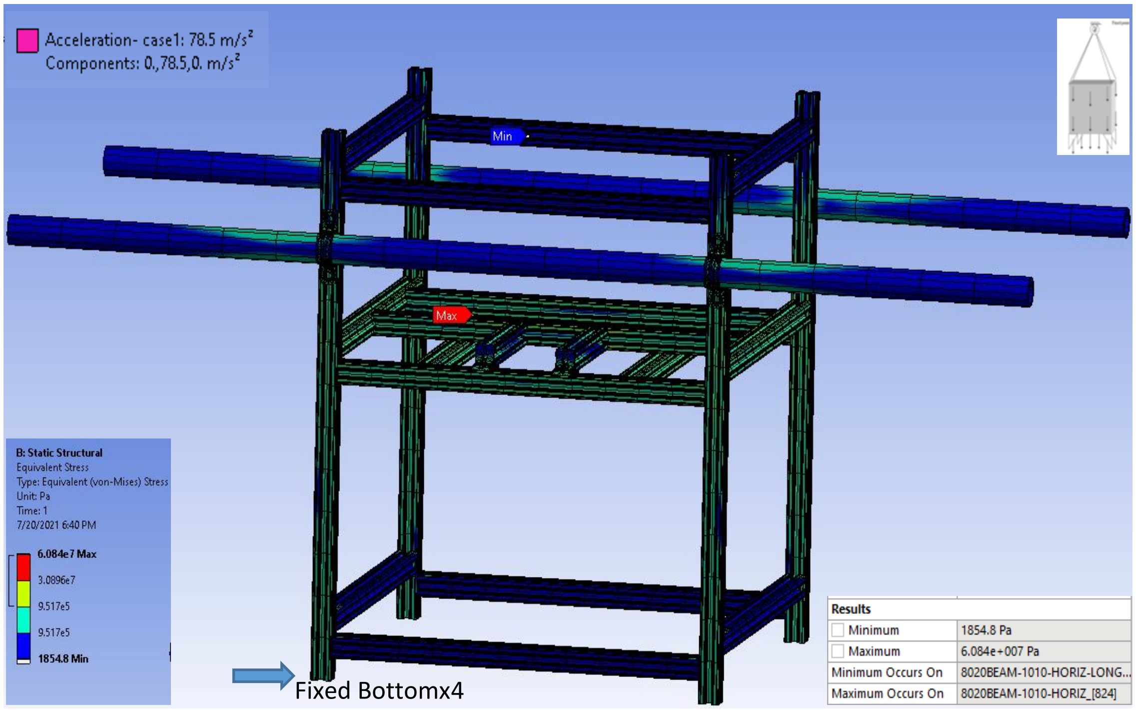

Figure 8: Equivalent Stress (True Scale)

Figure 9 has been scaled to 180x. It shows the maximum stress, marked in red, is located at the middle of the frame, where the top and bottom layers meet. This section is where the main components are located, therefore creating the most stress in the area. Furthermore, the image shows that the joints are not suffering any stress (blue), and those connections are stable.

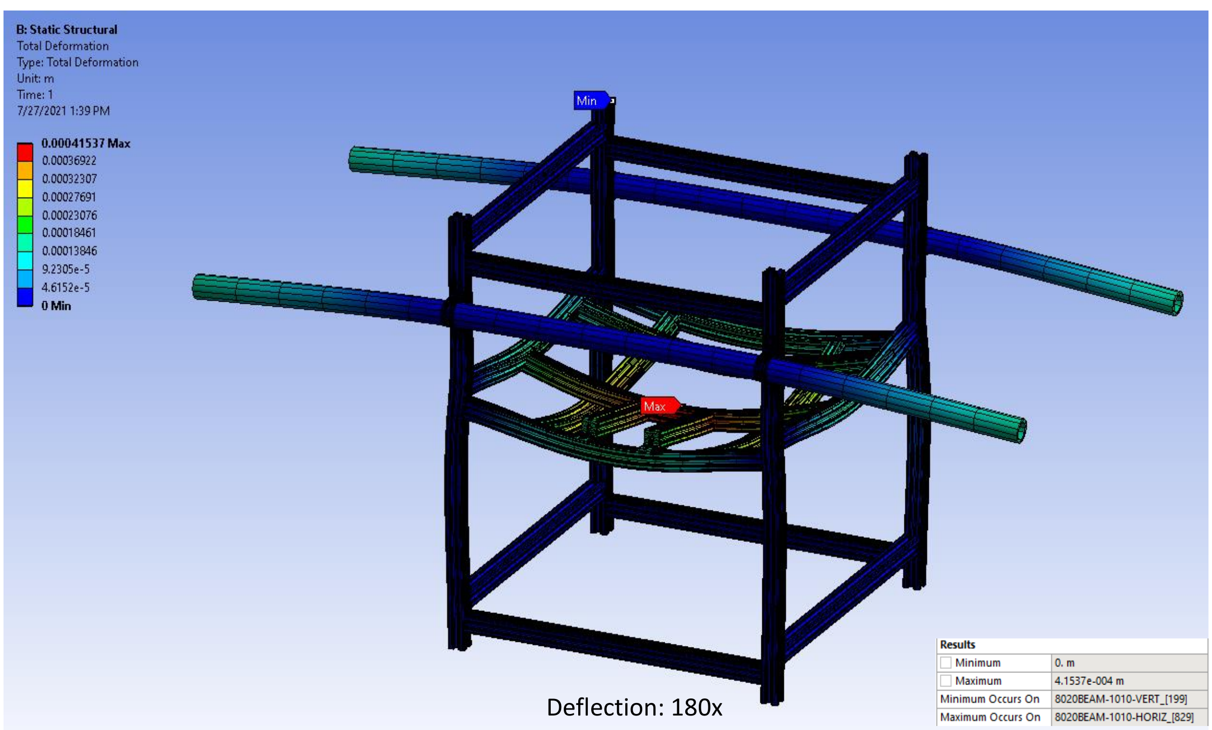

Figure 9: Gondola Deformation (Scale 180x)

B. 45⁰ Angle Analysis

The 45⁰ angle load case shown in Figure 10 shows the scenario where the parachute is deployed with 4G's of force being applied on only two cables (Load Case 3A). The other method (Load Case 3B) presents the same scenario where only one cable is attached when the parachute is deployed, leaving the gondola at a 45⁰ angle.

4.2.3 Load Case #3

A load 4 times the weight of the payload applied at the suspension point and 45 degrees to the vertical. This load factor must be accounted for in the direction perpendicular to the gondola's short side, long side, and in the direction of the major rigid support members at the top of the gondola structure. If flexible cable suspension systems are used, they shall withstand uneven loading caused by cable buckling.

Rationale: Assumes that the gondola rotates 45 degrees descends off-axis during termination and only one or two cables are loaded at parachute opening. It is to assure that the structure and attachments can handle this initial load.

Note: In reality, the load would be reacted through the gondola inertia and not the feet. For this reason, failure modes due to tension in the feet are not considered.

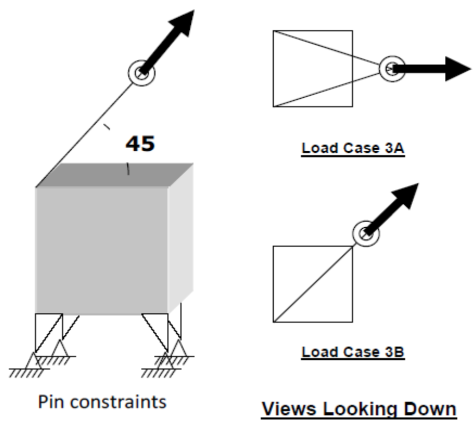

Figure 4: Load Case #3 – Off-Vertical Gondola Loading

Figure 10: 45 deg. angle Load Case.

When simulating the scenario for 3A, shown in Figure 11, the results showed the maximum stress at the handles clamps, as the forces would pull the most on those areas. The load case was 273.5lbf, and the maximum stress exerted on the handle clamps was 6.934 x 10^3 psi.

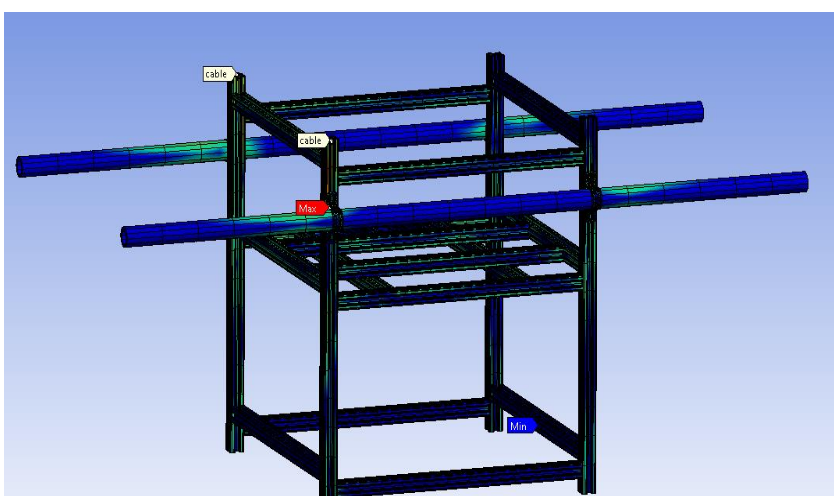

Figure 11: Results for Load Case 3A

For scenario 3B, the load case applied was the same as before 273.5 lbf, and the maximum stress exerted on the side of the cable attached was 1.7497×10^4 psi. Figure 12 shows that the maximum stress marked in red was located on the same side as the cable attachment.

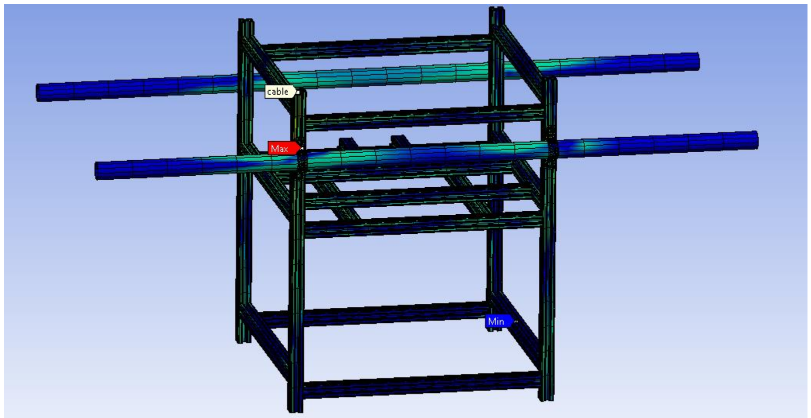

Figure 12: Results for Load Case 3B

C. Horizontal Load

The horizontal load showed in Figured 13 demonstrates the scenario where the parachute is deployed with 4G's of force being applied horizontally on the components inside the gondola.

4.2.4 Load Case #4

A lateral load of 4 times the weight of the payload applied to all components and equipment attached to and/or onboard the gondola structure or any portion of the flight system below the balloon at both principal lateral axes.

Rationale: Assumes that the gondola rotates 90 degrees descends off-axis during termination and inertial side loads are applied to components attached to the structure.

Note: Some components are analyzed individually and some are analyzed as part of the structural model. In non-symmetric situations, 4g is applied in both horizontal axis.

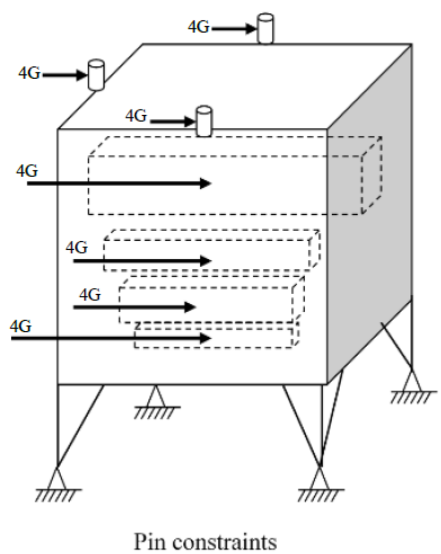

Figure 5: Load Case #4 – Gondola Lateral Loading

Figure 13: Horizontal Load Case

The case load applied for this case was 273.5 lbf, and the max stress exerted was 0.0542 psi and is marked in red in Figure 14. While the image does not show the components where loads were being applied, these loads were applied to the total mass of the instrument, battery box, and computer.

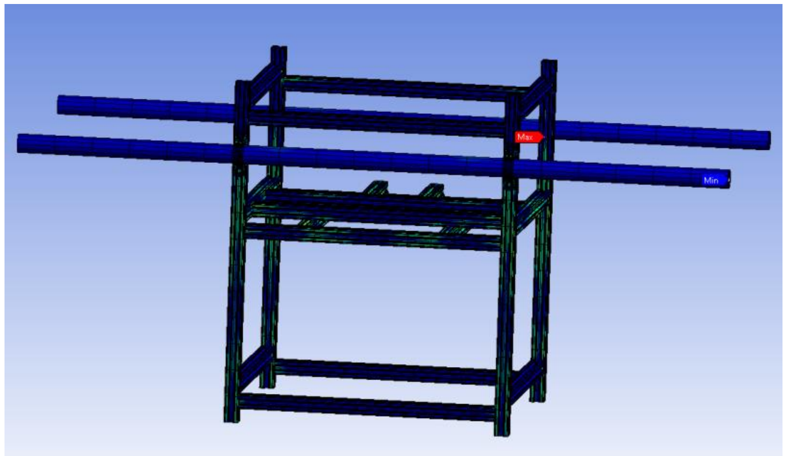

Figure 14: Results for horizontal load case

IV. Conclusion

The results from the different load cases scenarios are given in Table 3. These results are the margin of safety for each of the loads, and these margins determine if the gondola would be strong enough to survive the trip, the shock of the parachute deployment, and the landing.

Component	Load	Max Stress (psi)	Ultimate Strength * (psi)	Margin of Safety Ultimate	Yield Strength * (psi)	Margin of Safety Yield
CASE 1	8G Vertical	8824.09	38,000	3.07	34,968.6	3.17
CASE 3A	4G @ 45°	6934.25	38,000	3.91	34,968.6	4.03
CASE 3B	4G @ 45°	17,497.35	38,000	1.55	34,968.6	1.60
CASE 4	4G Horizontal	1960.91	38,000	13.84	34,968.6	14.27

Table 3: Margin of Safety

The blocks in green on the table indicate that the margins are above the minimum required, and the gondola will survive the different forces that it will encounter during its flight and landing. The formulas used to find the margin of safety are as follow[5]:

$$\text{MSu} = \frac{\text{Pu}}{\text{FSuP}} - 1 \quad \ldots (2)$$

$$MSy = \frac{Py}{FSyP} - 1 \qquad \ldots (3)$$

Where:
FSu is the ultimate Factor of Safety
FSy is the yield Factor of Safety
P is the limit load (or stress) calculated in the analysis
Pu is the load (or stress) at which material failure will occur
Py is the load (or stress) at which material yielding will occur
MSu is the Margin of Safety against ultimate failure
MSy is the Margin of Safety against material yielding

The calculations performed by the simulation and the Margin of Safety were proven correct, as Figure 15 shows the gondola being recovered almost intact. The only damage suffered during the landing was at the feet, where three didn't survive. Those were the expected results.

Figure 15: Gondola Recovery

V. Acknowledgments

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